FLOOD CRESTS ON THE OHIO AND MISSISSIPPI, AND THEIR MOVEMENT.

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SYNOPSIS.

This study is based on the results of daily gagings of the Ohio and Mississippi Rivers under the varying conditions of stream flow that may arise in the course of a year.

The actual velocity of flood flow for a number of freshets and flood flows have also been considered.

Owing to the difficulty in evaluating the influence of some of the important factors that determine the velocity of flow of water in open channels, no simple formula of general application has yet been developed.

While the velocity of flow of water in an open channel is greater the higher the stage and is greater in a rising than in a falling river, yet the movement of crest stages—not being dependent wholly upon the velocity of flow—appears to be more rapid at comparatively low stages when the water is well within the banks of the stream than when the banks are overtopped as at very high stages. The reasons are fairly obvious although local conditions and the tributary effect may be the dominating influence as at Cairo, Ill., where, at times, the balance between inflow and outflow is disturbed by the channel capacity below Cairo. Overflow of lowlands on the left bank opposite and immediately below Cairo at stages above 40 feet results in more or less retardation in the velocity of the outflow and crest stages on the Cairo gage may be due to that cause alone.

The average rate of flood flow in the upper Ohio is about 5 miles per hour and on the Mississippi below Cairo very close to 4 miles per hour, although crest stages move at a slower rate.

In the practical work of forecasting the date of occurrence of flood crests it becomes important to have a clear understanding of the conditions which precede and attend the rise of a flood and its subsequent movement down stream.

The flow of water in open channels.—The flow of water in natural and artificial channels has been under observation for more than a century and much time and energy has been expended in the development of a formula which shall truly represent the mean velocity of a stream. The basic formula for the velocity of water as an element in estimating the discharge of a stream is that of Chezy (1775).

$$v = c\sqrt{r\ s}, \text{ in which}$$

v is the mean velocity in feet per second; c a coefficient combining the total effects of the roughness of the bed and all other conditions which may effect the velocity except the two remaining terms (r) hydraulic radius and (s) slope. Ganguillet and Kutter[1] (1869) succeeded in expressing the coefficient c in terms of r, s, and n in which r and s have the same significance as in the Chezy formula and n is a separate factor to indicate roughness, and should be estimated upon data collected in the field.

The equation as developed by Kutter is complicated and for obvious reasons its application to conditions of flood flow is exceedingly difficult. The movement of a flood down the stream channel can be determined with considerable accuracy by gage readings especially when the range from low to high water is great and tributary effects are absent. The simplest case is that of the sudden release of a large body of water as by the failure of a dam. The rapidity of movement of the resulting flood wave downstream will depend largely upon the general water level at the time of the failure of the dam. If at a very low stage the speed of the flood wave will be much retarded both on account of greater friction upon the bed and sides of the channel and because of the time consumed by the flood waters in filling the pools and low places in the channel and also in overflowing the low spots in the flood plain. With the water at a moderate stage the flood flow will be more rapid and will closely approximate that of a moderate flood produced by natural causes.

The most important factors affecting the flood flow of a stream are the size and shape of the watershed and its geographic position with respect to the prevailing direction of rain storms which pass over it. The larger the watershed the less the likelihood of torrential rains falling over its entire area and therefore the less the probability of a severe flood. Even though torrential rains should fall over one or more of the smaller tributaries of the watershed the resulting flood wave will flatten out when it reaches the main stream.

A drainage area so shaped that the discharge from its tributaries will reach the trunk stream at about the same time will promote the occurrence of maximum floods. A watershed in which the drainage is in a direction opposite to that in which rain storms advance is favorably conditioned with respect to the slow rise of floods since a part of the flood waters has an opportunity of running off before the flow from the headwaters can reach the lower part of the stream.

River gagings separated by an interval of 24 hours serve but imperfectly in determining the speed of crest movement. In the Weather Bureau service the endeavor is made to have river observers note and record the time of occurrence of the crest stage but more frequently than not the time of occurrence of the crest stage is not obtained.

On a small watershed, whatever its shape, the rainfall distribution is generally uniform and the discharge from the tributary streams will as a rule reach the trunk stream at very nearly the same time.

The run-off which first reaches the stream is that from the zone of 50 or more miles in width paralleling the channel. The run-off from this zone for convenience may be called the "immediate" run-off. The first effect of this run-off is to cause the pools in the channel to be filled up and naturally a rise in the river that is practically simultaneous throughout its entire length. As the run-off from the more remote parts of the watershed reach the trunk stream a definite crest stage which may be a few inches or a few feet in magnitude is reached at and immediately below the junction of the upper main tributary streams with the trunk stream. Whether the crest will increase in magnitude or flatten out as it passes downstream is conditioned almost wholly upon the run-off of the tributaries that join the trunk stream in its lower reaches. It may happen that the run-off of the lower tributaries has reached the trunk stream in sufficient volume to cause a definite crest stage before the the arrival of upstream water and that the arrival of this water merely tends to retard the fall and thus prolong the flood wave. In all such cases the movement of the upstream crest can not be followed. Again it may also happen that after a rainy period of several days duration the rains in the upper part of a watershed may be sufficient to start a moderate flood wave downstream. This flood wave advancing successively into stretches of a rising stream moves with a speed closely approximating that of the maximum of flowing water in a stream.

An example of a flood wave that apparently passed from Warren, Pa., to New Orleans, La., in 19 days, or at

[1] Ganguillet & Kutter, The Flow of Water in Rivers and Other Channels, English Translation, 1889.

the rate of about 100 miles per day, is afforded by the freshet of October-November, 1917. This freshet occurred at a time when all streams were at a low stage; it was caused by short period of almost daily moderate showers in the watersheds of the northern tributaries of the Ohio extending from Indiana to western Pennsylvania and was followed by about three weeks of rainless weather thus giving an opportunity to follow the rise downstream without the usual complications which arise from the tributary effect due to rains after the crest has been reached. On examining the record more closely it was found that there were at least two distinct crests separated by about a week and that the second crest overtook the first at Cincinnati, Ohio, about October 30; thereafter, while the progress of the first wave can be shown by the daily rise there was a steady and more or less continuous rise to the principal crest a few days later.

Below Baton Rouge the indications as to the date of the crest are uncertain, but it probably occurred at New Orleans on the 19th.

The details of the progress of both crests are shown in the subjoined table, and the advance of the rise on the Mississippi, Cairo to New Orleans, is illustrated in figure 1.

River and station.	First rise.				Second rise.				
	Date, 1917.	Stage feet. From—	Stage feet. To—	24-hour rise.	Date.	Stage feet. From—	Stage feet. To—	24-hour rise.	Above Cairo (miles).
Allegheny.									
Warren, Pa	Oct. 20	0.7	4.2	3.5	Oct. 30	9.7	12.8	3.1	1,114
Franklin, Pa	...do.....	2.1	4.5	2.4	Oct. 31	9.4	12.4	3.0	1,081
Parkers, Pa	...do.....	2.0	4.3	2.3	...do.....	12.8	14.7	1.9	1,040
Freeport, Pa	...do.....	4.1	10.0	5.9	...do.....	15.9	19.1	3.1	996
Ohio.									
Pittsburgh, Pa	Oct. 20	6.0	6.5	0.5	Oct. 31	11.9	14.4	2.5	967
Wheeling, W. Va	...do.....	3.3	10.0	6.7	Nov. 1	21.1	21.6	0.5	879
Parkersburg, W. Va	Oct. 21	11.0	12.7	1.7	Nov. 2	22.0	22.1	0.1	784
Point Pleasant, W. Va	Oct. 20	7.1	11.3	4.2	...do.....	22.7	24.0	1.3	703
Huntington, W. Va	...do.....	7.5	12.3	4.8	...do.....	24.0	25.0	1.0	657
Portsmouth, Ohio	...do.....	4.8	11.0	9.2	Nov. 3	27.4	28.2	0.8	612
Cincinnati, Ohio	Oct. 22	[1] 12.5	15.5	3.3	Nov. 4	27.5	28.0	0.5	499
Madison, Ind	...do.....	9.3	11.9	2.6	Nov. 5	22.7	23.0	0.3	412
Louisville, Ky	Oct. 23	9.1	9.3	0.2	...do....	10.4	10.5	0.1	367
Cloverport, Ky	Oct. 25	8.8	11.0	2.2	Nov. 6	20.3	20.6	0.3	200
Evansville, Ind	Oct. 26	8.5	11.4	2.9	Nov. 7	20.2	20.5	0.3	181
Shawneetown, Ill	...do.....	5.4	9.0	3.6	...do.....	19.6	19.8	0.2	119
Paducah, Ky	Oct. 27	4.2	6.2	2.0	Nov. 8	14.4	14.5	0.1	43
Cairo, Ill	Oct. 28	9.6	11.5	1.9	Nov. 9	19.1	19.2	0.1	....
Mississippi.									*Below Cairo.*
New Madrid, Mo	Oct. 29	8.1	9.0	0.9	Nov. 9	13.8	14.0	0.2	71
Memphis, Tenn	Oct. 31	5.6	7.2	1.6	Nov. 12	12.3	12.6	0.3	227
Helena, Ark	Nov. 1	5.2	6.6	1.4	...do.....	13.9	14.2	0.3	307
Arkansas City, Ark	Nov. 2	6.4	7.7	1.3	Nov. 14	16.2	16.5	0.3	437
Greenville, Miss	Nov. 3	5.8	6.8	1.0	...do.....	11.3	11.6	0.3	480
Vicksburg, Miss	Nov. 4	4.3	5.3	1.0	Nov. 16	12.5	12.6	0.1	602
Natchez, Miss	Nov. 5	6.0	6.9	0.9	Nov. 17	13.7	13.8	0.1	706
Baton Rouge, La	Nov. 7	3.2	3.7	0.5	Nov. 18	7.0	7.3	0.3	841
New Orleans, La.[2]	....	....	....	....	....	....	....	....	964

[1] Pool stage.

[2] Crest dates uncertain, probably second on Nov. 19.

Attention is directed to the fact the the first or preliminary crest was reached on the Ohio from Portsmouth almost to the headwaters of the Allegheny in northern Pennsylvania on October 20, excepting only a short stretch of the river between Marietta, Ohio, and Parkersburg, W. Va., where the discharge from the Muskingum came out a day later. This rise in the streams from a low stage was due to very general rains on the 19th over the entire basin. There was no pronounced flood peak at any point along the river, although the discharge of the tributary streams which enter the Ohio on the right bank between Pittsburgh, Pa., and Cincinnati, Ohio, was sufficient to create a distinct rise in the river which can be traced more or less definitely from the headwaters to New Orleans, La.

The column in the table headed "24-hour rise" shows roughly the volume of flood flow that passed the respective gaging stations. The relation between gage heights and discharge for the stations in the table is of course not a fixed one nor are the gage heights at the several stations strictly comparable among themselves, although the gaging stations on the Ohio above Cincinnati are fairly comparable. The river at Madison, Ind., and below is considerably wider than at points upstream. This is especially true for Louisville, Ky., where the river at bankful stage is 3,400 feet wide, almost twice as wide as at Cincinnati. The gage relations between the two stations vary within very wide limits. At extremely low stages a rise of a few feet at Cincinnati may not show on the Louisville gage and, on the other hand, at a 50-foot stage on the Cincinnati gage, and a corresponding high river below 75 per cent of the rise at Cincinnati will show on the Louisville gage.

The weather after October 20 was showery with rains almost daily in some part of the basin, so that the streams rose quite generally.

On the 30th a general and moderately heave rain occurred over the upper Ohio basin, producing the rises shown in the table under the caption "Second rise."

The speed of the first rise computed from crest stages, Cincinnati to Cairo, was approximately 3.4 miles per hour, and from Cairo to Baton Rouge, La., 3.5 miles per hour.

The bulk of the run-off from the rains of October 30 appears to have reached the Allegheny throughout its entire length on the 30th–31st, October. Although the crest stages on that stream occurred some time after 8 a. m. of the 31st. The crest at Pittsburgh was reached at 11 a. m. on that date and by the next morning the river was falling throughout its entire length. The crest at Wheeling, 87 miles below Pittsburgh, was reached in 13 hours, or at the rate of 6.7 miles per hour. The crest at Parkersburg, 95 miles below Wheeling, was reached in

23 hours, or at the rate of but 4.1 miles per hour. No definite times of the occurrence of the crest were reported below Parkersburg and we must therefore assume that the 8 a. m. readings correspond to the crest stages at points on the lower river. The velocity thus computed is 4.4 miles per hour.

From Cairo to Baton Rouge the velocity was about 4 miles per hour as compared with 3.5 miles for the first rise; it should be remembered, however, that in reality the second rise merged almost imperceptibly into the first from below Cincinnati to Natchez which doubtless accounts for the rapidity of movement.

Instead of using gage heights in determining the time of occurrence of the crest stage we may consider the time interval between successive rises of some definite magnitude, say 1 or 2 feet between stations located at varying distances below the headwater stations. When, for example, a river is falling or stationary an increase in gage height can be interpreted in but one way, viz, as showing an increase in streamflow, channel conditions remaining the same. The increase in streamflow first noticed at a gaging station is generally the result of what has been hereinbefore called the "immediate" run-off but when the rise is pronounced we may note the time required for a rise of similar magnitude to reach the gaging station next below. The 24-hour rises in the Mississippi from Chester, Ill. (115 miles above Cairo, Ill.), to New Orleans, La., for the period during which the two freshets hereinbefore described passed down stream have been plotted to form figure 1 below.

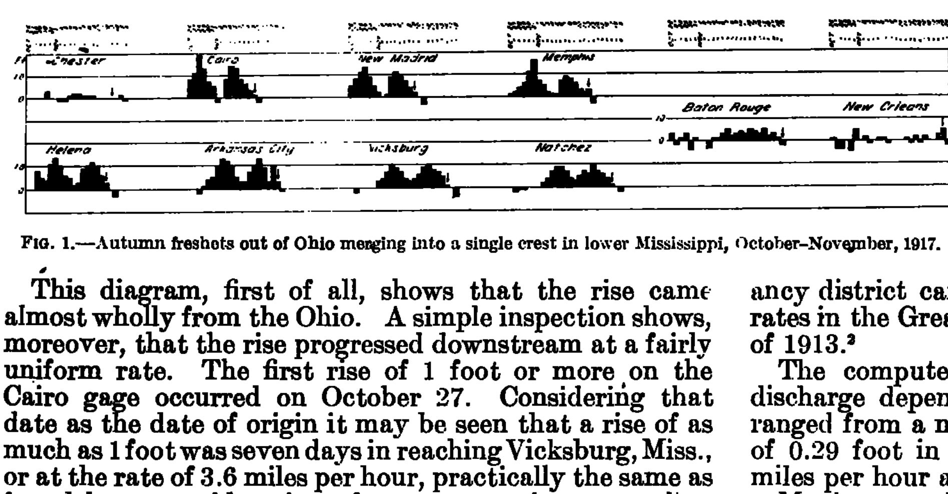

FIG. 1.—Autumn freshets out of Ohio merging into a single crest in lower Mississippi, October-November, 1917.

This diagram, first of all, shows that the rise came almost wholly from the Ohio. A simple inspection shows, moreover, that the rise progressed downstream at a fairly uniform rate. The first rise of 1 foot or more on the Cairo gage occurred on October 27. Considering that date as the date of origin it may be seen that a rise of as much as 1 foot was seven days in reaching Vicksburg, Miss., or at the rate of 3.6 miles per hour, practically the same as found by a consideration of crest stages in a preceding paragraph. The second rise on the Cairo gage was not so great as the first and was separated therefrom by a period of but 24 hours during which time the river remained stationary at 13.8 feet—a stage about 5 feet higher than when the initial rise began on October 26. This second rise, as may be seen from the diagram, progressed downstream a little more rapidly than the first. Considering the rise of 0.8 foot at Cairo on November 3 as the reference datum the progress of the rise downstream is shown in the small table below.

Station.	Initial rise.	Date.	Maximum rise.	Date.
Cairo, Ill.	0.8	Nov. 3	1.4	Nov. 4
New Madrid, Miss	0.9	Nov. 4	1.1	Nov. 5
Memphis, Tenn	0.7	Nov. 6	0.9	Nov. 7
Helena, Ark	0.9	Nov. 7	1.2	Nov. 9
Arkansas City, Ark	0.7	Nov. 8	1.3	Nov. 10
Vicksburg, Miss	0.6	Nov. 10	1.0	Nov. 12
Natchez, Miss	0.7	Nov. 11	1.0	Nov. 13
Baton Rouge, La	0.5	Nov. 12	0.5	Nov. 15

The distance from Cairo to Baton Rouge, 841 miles, was covered in 9 days, or at the rate of 3.9 miles per hour. The slight difference in speed between the first and second rise may be accounted for by the fact that the river stood a little higher at the beginning of the second rise than at the beginning of the first.

MEASURED VELOCITIES OF STREAM FLOW.

Since the velocity of flow is an important factor in the determination of discharge, many careful and accurate measurements of the actual velocity of flow are available. The early observations by Humphreys and Abbot on the Mississippi, as well as the later observations by the Mississippi River Commission, have been considered. A casual inspection of these observations shows at once that the velocity is greater for rising than for falling stages and that owing to wind action and possibly other local influences different velocities are sometimes indicated within comparatively short sections of the river. Discharge observations made at Columbus, Ky., for stages of 40 feet and above with a rising river give an average velocity of 5.3 miles per hour. For approximately the same stage, but for a falling river, the average velocity was found to have been 4.6 miles per hour. At stages of about 30 feet the observations are not so numerous as at 40 feet, but the excess in the velocity of flow for a rising river appears to be greater than at the stage of 40 feet.

Observations at Vicksburg, Miss., for stages between 40 and 45 feet and a rising river give an average velocity of 4.6 miles per hour and for a falling river at the same stages 4.3 miles per hour.

Observations in the Mississippi River above Carrollton, La., during the flood of 1912 and 1913 give average velocities in the main channel of 4.1 and 3.9 miles per hour, respectively, for the two floods. These observations were made on a rising river.

The engineers of the Miami conservancy district carefully computed the maximum discharge rates in the Great Miami and tributaries during the flood of 1913.[3]

The computed velocities at the time of maximum discharge depend very considerably upon slope. They ranged from a maximum of 2.7 miles per hour at a slope of 0.29 foot in 1,000 to an individual maximum of 10 miles per hour at a slope of 3.5 feet in 1,000.

Maximum velocities greater than 6.5 miles per hour were very rarely observed in the Mississippi.

In general, the maximum velocity of flowing water in the lower Mississippi during high water is close to and probably slightly in excess of 4 miles per hour. It is probable that maximum velocities as great as 4.5 miles per hour may be experienced in the front of the flood wave, but since the flood front is naturally of limited extent an average value of 4.5 miles is considered too high.

The average interval between flood crests, Cairo to Memphis, as empirically determined is about 5 days with a possible variation of as much as 40 per cent. The interval is nearly always greater for high water—a stage of 50 feet or over on the Cairo gage—than for low water. For Cairo stages between 20 and 40 feet the average interval is very close to 3 days, which corresponds to a speed of 3.1 miles per hour for the most rapid moving crests. The great flood crests appear to move on the average with

[3] Miami Conservancy District. Technical Reports, Part IV, Table No. 3, Ivan E Houck.

a speed of 1.9 miles per hour. The average interval for great flood crests between Cairo and Vicksburg is about 16 days with a possible variation of 3 or 4 days on either side. This corresponds to a speed of about 1.5 miles per hour.

A further example of rapid crest movement is that afforded by the

AUTUMN FRESHET OF 1918.

This freshet had its origin in the rains of October 30, 31, in the Ohio watershed, mostly over the southern tributaries. Its beginning was not clearly marked, but it may be said to have passed from Pittsburgh, Pa., to New Orleans, La., in about 22 days, increasing in magnitude as it passed downstream, the increase being due to a fortunate combination of the tributary freshet flow with that of the main stream. The tributaries concerned were the Kanawha, the Big Sandy, the Kentucky, and the Tennessee and Cumberland, all southern tributaries. It so happened that the rainfall on the headwaters of the two last mentioned was unusually heavy on October 30, a day sooner than on other tributaries, and, although the flood waters of both these streams had a greater distance to cover, they synchronized fairly well with the flood flow coming down the Ohio. Thus it happened that with a total rise of but 3.6 feet at Pittsburgh to a stage of 9.9 feet on November 1, the total rise at Cairo had increased to 12.5 feet and the stage reached was 23.2 feet. This rise was sufficient to carry through to New Orleans in about 14 days and to Vicksburg in 8 days, the latter being one among the most rapid movements ever experienced. The progress of this freshet is graphically shown in figure 2. An analysis of this illustration discloses the following: The rise in the Ohio at Pittsburgh and Wheeling had diminished to about one-third of its volume as measured by gage heights when it reached Parkersburg. A sharp rise in the southern tributaries below Parkersburg reaching the trunk stream 24 hours before the up-river water had arrived, advanced the date of the crest between Point Pleasant and Cairo by that amount. At Cincinnati and Madison the river rose about a foot on October 31, evidently due to the same rainstorm that caused the rise at Pittsburgh and Wheeling a day later. This rise can be definitely traced to Cairo, but appears to have lost its identity at New Madrid, although it reappears at Arkansas City and below; hence we have, as before, a series of rather small rises progressing downstream and separated from each other by a very short time-interval. This condition appears to be conducive to the maximum rate of flow.

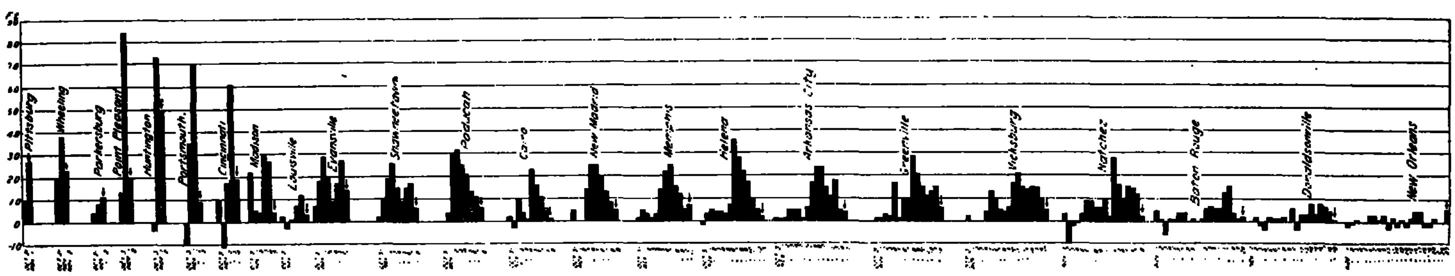

FIG. 2.—The autumn freshet of November 1, 1918, Pittsburgh to New Orleans in 23 days.

Still another example of the movement of flood crests at initially low stages is afforded by the freshet in the lower Ohio and the Mississippi below Cairo produced by the exceptionally heavy rains that fell within 60 hours over southwestern Ohio, southern Indiana and Illinois, and western Kentucky, October 3–6, 1910. Over this region the rainfall was nowhere less than 6 inches and in localities as much as 15 inches. The streams were low and the ground was dry, hence a damaging flood did not result. The heavy rainfall was confined to the regions above named and there was no pronounced rise in the Ohio above Cincinnati. At that place the river rose 10.6 feet in 48 hours; at Evansville the total rise was 21.1 feet in 7 days and at Cairo 14.6 feet to a stage of 26.8 feet in the same time. This rise was sufficient to carry through to New Orleans although the date of arrival at that place is more or less uncertain. The rate of movement from Cairo to Memphis was 4.7 miles per hour; Memphis to Vicksburg, 3.1 miles per hour. It is probable that the high velocity, Cairo to Memphis, was due in a measure to the heavy rain that fell directly into the channel and over the area between the levees. The total rainfall at Memphis, October 3–6, was 4.73 inches; Cairo, 10.92 inches, and, of course, proportionate amounts between these two points. The response of the river at Cairo and Memphis to the run-off from this rainfall is shown in the small table below.

Rise of the Mississippi in feet and tenths on the dates and at the places named.

Date.	Cairo.	Memphis.
Oct. 5	0.9	0.1
Oct. 6	3.9	0.7
Oct. 7	4.0	0.6
Oct. 8	1.6	2.0
Oct. 9	2.3	2.7
Oct. 10	1.6	2.1
Oct. 11	0.3	1.7
Oct. 12	....	1.2
Oct. 13	....	0.6

These figures show that the main rise which began at Cairo on the 6th appeared two days later at Memphis. Up-river water at Cairo did not arrive until the 9th and it was doubtless due to that fact that the crest both at Cairo and Memphis was reached on the 11th and 13th, respectively. Figure 3 illustrates the progress of this freshet.

I pass now to a consideration of the movement of a well-defined flood on the Ohio due to rain and melting snow. The flood selected is that of January 8–26, 1913. This flood had its origin in a few days of relatively high temperature with rain over practically the whole of the Ohio basin. The high temperature caused much snow water to reach the trunk stream and the subsequent weather was favorable to continued high run-off until near the close of the month. The distribution of the run-off from melting snow is different from that of rainfall in that while a rainstorm generally passes across the entire watershed in 24 hours and the run-off therefrom ceases shortly after the end of the rain, the discharge from melting snow continues uninterruptedly so long as the temperature remains substantially above freezing. In the case under consideration the temperature was considerably above freezing for upwards of 70 hours and longer over the southern tributaries. As a result the Ohio from Pittsburgh to Cairo rose continuously and rather uniformly for several days; the average rise on the 8th was 7.6 feet, on the 9th 7.6 feet, on the 10th 4.3 feet, on the 11th 2.7 feet, on the 12th 3.8 feet, and on the 13th 2.4 feet.

When a stream is rising from its source to its mouth there can be no real pronounced crest except as some tributary contributes an unusually large volume of water. In this case the run-off from melting snow in the Allegheny and other rivers that converge at Pittsburgh was checked on the 9th and the flood crested at Pittsburgh on that date. The crest was reached at Wheeling 86 miles downstream on the 10th, but the river at Parkersburg 183 miles downstream continued to rise until the 13th. Between Parkersburg and Cincinnati a large volume of water was discharged into the trunk stream and as a consequence the flood at Cincinnati was in the form of a long drawn out swell without a pronounced crest, although the highest point reached was 62.2 feet at 6 p. m. of the 14th, 0.3 foot higher than at 8 a. m. of the same date. The river at Cincinnati remained above the 60 foot stage for about 5 days. Below Cincinnati the flood wave was of similar form, the river rising by a small amount each day and finally cresting at a stage only a small fraction of a foot above the stage 24 hours preceding. The crest of this flood appears to have passed from Pittsburgh to Cincinnati at the rate of 4.4 miles per hour and from Cincinnati to Cairo at the rate of 1.8 miles per hour. The time required for this flood to pass Cincinnati and the relatively high stages in both the Tennessee and Cumberland foreshadowed a slow crest movement in the lower river.

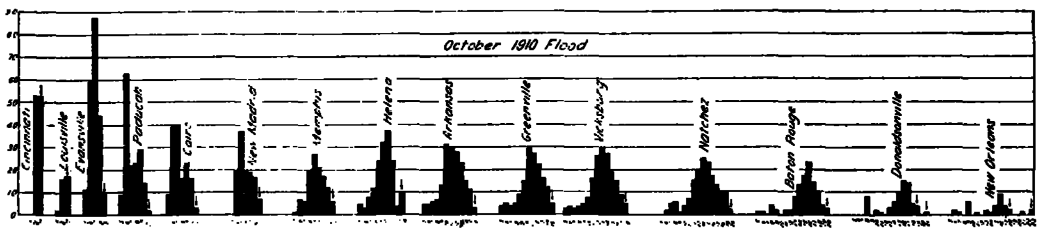

FIG. 3.—Freshet of October, 1910, due to heavy rains in lower Ohio Valley.

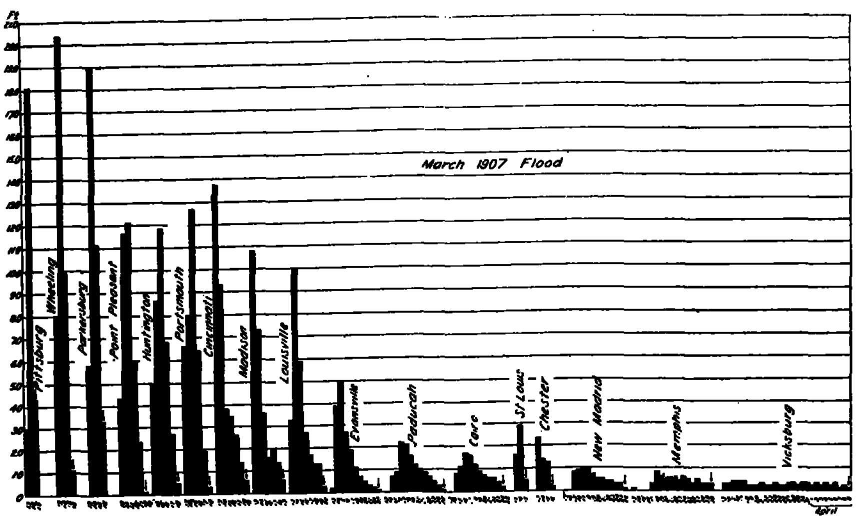

FIG. 4.—The great snow flood of March, 1907, in upper Ohio.

The severe flood of March, 1907, in the upper Ohio affords an example of an intense flood in the headwaters of a stream which flattens out as it reaches the lower reaches because of inadequate tributary support.

The flood in question was due to a combination of heavy rain irregularly distributed, moist snow, and high temperature; the latter continued over two days and caused a run-off from melting snow sufficient to cause a break-up of the ice in the main streams and their tributaries. The high temperature on the 14th was effective in producing a crest stage in both the Youghiogheny and Kiskiminetas, two of the main tributaries of the Ohio that converge close to Pittsburgh, and it was mainly to the very heavy flood flow of these two rivers that an unprecedented stage was reached at Pittsburgh on the early morning of the 15th. The Muskingum, which enters the Ohio on the right bank at Marietta, Ohio, contributed a large flow on the 15th which had the effect of advancing somewhat the time of the crest in the Ohio at Parkersburg. The exact time required by the crest to pass from Pittsburgh, Pa., to Louisville, Ky., was 126 hours, or at the rate of 4.8 miles per hour; from Louisville to Cairo the rate of movement was diminished to 3.6 miles per hour. The Mississippi at Cairo, when the Ohio flood reached it, was at a moderate stage and slowly falling. The crest of the Ohio flood reached Memphis in 6 days, Vicksburg in 16 days, and New Orleans in 20 days. The 24-hour rise during the early part of the flood is graphically shown in figure 4 for the stretch of the river—Pittsburgh, Pa., to New Orleans, La.

In general, it may be said that the average crest movement Pittsburgh to Cincinnati is 3.4 days, Cincinnati to Cairo 6.6 days, and Pittsburgh to Cairo 10 days, with wide departures due to the tributary effect of the Tennessee and Kentucky Rivers.

For the Mississippi the crest movement Cairo to Memphis for floods of 50 feet on the Cairo gage is very close to 5 days, with a possible variation of a day on either side; for great floods Cairo to Vicksburg the average interval is 16 days, with a possible variation of 4 days on either side due to tributary effects below Memphis. Crest stages of small floods and freshets travel with almost twice the speed of the crests of great floods.

Mr. Herman W. Smith of the river and flood division has also determined the time interval between Cairo, Ill., and Vicksburg, Miss., respectively, and the relation which subsists between crest stages at the two places. His note and the illustrations which accompany it may be used as a basis for forecasting crest stages at Vicksburg as soon as the crest has been reached at Cairo.